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Energy security in Bangladesh perspective—An assessment and implication

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ABSTRACT

Energy is a key indicator of the nation′s overall economic as well as social development. Looking at the present energy demand scenario in Bangladesh, electricity demand has significantly increased over the past years. Most of the Bangladesh′s power plants are heavily dependent on expensive imported fossil fuel energy resources. Thus, the power failure has become an acute problem for the country and adversely affects the socio-economic development of the country. Consequently, the shortage and constraint in availability of fossil fuels appeal to boost up the renewable energy sector in Bangladesh in order to bring down the gap between demand and supply. Hence, decisive steps to reform the power sector with a mandate to oversee these sectors urgently need to overcome current energy crisis facing in the country. In this paper, efforts have been made to summarize the availability, current status, strategies, perspectives, promotion policies, major achievements and future potential of energy options in Bangladesh.

Contents

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1. Introduction

Currently, the world's growing thirst for oil amounts to almost 1000 barrels a second [1]. In consequence, the inadequacy of fossil fuel and the increase in demand of energy are the driving force concerning the future energy security around the world. According to the Ludwing Boltzmann, the important issue of the 21st century is the energy security.

"The struggle for existence is the struggle for available energy" [1].
Ludwig Boltzmann

As forecasted by International Energy Agency [2], the reserves of coal, oil and natural gas will be exhausted by 122, 42 and 60 years, respectively. Further, the projections of the International Energy Outlook [3] highlighted that the price of oil on the international market will reach U$$133 per barrel in 2035. The trend of on-going high prices for oil is likely to aggravate the imbalance in the trade balance of countries which are dependent on the import of oil and its derivatives [4].

Bangladesh has been facing an extreme shortage of electricity over the past decade. The production status of energy in Bangladesh has not been match to the power requirements of various categories of consumers [5–7]. Hence, there was a power failure in the industrial as well as agricultural sector, which means food insecurity and less production. These in turn, leads to lesser income; lessen capital formation, lesser exports and slow economic growth [8,9]. However, it is not possible to any of the reasons causing scarcity of energy in Bangladesh. A combination effect of financial, structural, and socio-political is responsible for the acute shortage of electricity in Bangladesh; none of them can be mutually exclusive. It was highlighted by Islam et al. [10] that infrastructure in energy sector has become supremely important for a nation's economic development, as it provides the basic structural foundation for it. This infrastructure is like the wheels of economic activity [11]. Hence, it is reasonable to state that the economic progress depends very much upon how successfully and profitably a country manages its power sector.

The energy conservation through improved energy efficiency, a reduction in fossil fuel use and an increase in environmentally friendly energy supplies are the prime movers ensuring the country's future energy security [12]. Several technologies are available for the production of clean, efficient and reliable energy, such as wind, sun, water, biomass and biogas, tides and waves, hydrogen and geothermal energy [5,13,14]. Jacobson [15] ascertained that the flourishing of renewable energy resolved the environmental pollution and global warming problem. A conclusion has been reached by Jean-Baptiste et al. [16] who reported that the nuclear energy have a low impact on climate change. Further, the development of renewable energy could be one of strategic approach of the country to reduce the dependency on oil exploration country [17]. However, the challenge is how to harness further energy services in sustainable, adequate, affordable ways. Specifically, appropriate strategies, in terms of policies, mechanisms and institutional setting for the advancement in energy sector are important for the country. This paper focuses current status of primary energy, power sector, power generation strategies, promotion policies and major achievements in Bangladesh. It also presents potential of renewable energy options for power generation to improve energy security in Bangladesh.

2. Primary energy supply in Bangladesh

The supply of energy is the major social challenges which amplify the provision of basic services in life. The high degree of uncertainty in the resources for power production and the cost of

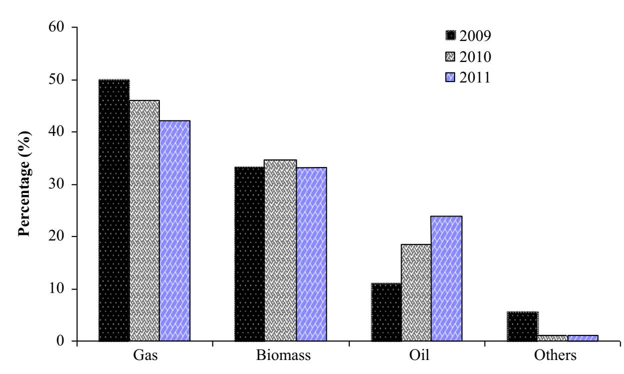


Fig. 1. Share of total internal energy resources in Bangladesh [18].

energy would deter investment, which is highly dependent on the primary energy resources. Share of total internal energy resources in Bangladesh has been compared in Fig. 1.

Natural gas and heavy fuel oil are the prime movers for internal supply of energy of the country (Fig. 1). The natural gas plays an important role in the growth of the national economy, as a major internal source of energy. According to the finance division [19], Bangladesh has 20.5 trillion cubic feet (TCF) of proven gas reserve as of 2012, in which 10.4 TCF gas has already been recovered. It was reported by Chowdhury [20] that the reserve of natural gas in Bangladesh would last up to 2017, possibly up to 2020, if the consumption of gas for electricity generation continues at a present rate. Hence, an approach on sustainable development of energy sector in Bangladesh is a crucial issue to meet the future energy demand.

Biomass is the most important source of energy in Bangladesh, as the country produces a huge amount of biomass from agriculture residues, wood wastes, animal dung and municipal solid waste in every year [10,13]. Total energy supply especially, non-commercial energy sources (biomass), such as wood, animal wastes, and crop residues, are estimated to account for the second largest sources of primary energy. As reported by Ahiduzzaman et al. [21], 78% of the total population in Bangladesh uses biomass for cooking, as a main source of energy. However, most of the electric power and industry of the country is used oil and gas as a source of power. It may be mentioned that the availability of sufficient power is an index of economic development [22]. Unless power is sufficiently available to the industrial sector, the country cannot be progress industrially. Thus, the industrial backwardness in today's world is an indication of economic backwardness. Most of the commercial power sectors in Bangladesh use oil and gas, as a source of electricity.

The sectoral use of natural gas in Bangladesh is illustrated in Fig. 2. As can be seen from Fig. 2, the main sectors utilizing gas energy are the power and industrial sectors, which account for 42% and 17% of total usage, respectively. The remaining energy is supplied to the captive (16%), fertilizer sectors (7%), the household sector (11%) and others (7%). However, supply of natural gas in household sector is being hindered by poor gas transmission and network distribution. It was reported by Ahmed [23] that currently the total gas output is around 2180 million cubic feet per day (mmcfd) against its demand of 2500 mmcfd. However, the actual demand will be higher when the awaiting industries and housing units will get connection with the gas line [23].

Fig. 3 illustrates the sectoral use of petroleum fuel in Bangladesh. According to the Bangladesh Petroleum Corporation (BPC), transportation sector is the largest consumer of petroleum fuel with 45% of total consumption. The fuel consumptions for other sectors are agriculture 21%, power (19%) and domestic (9%).

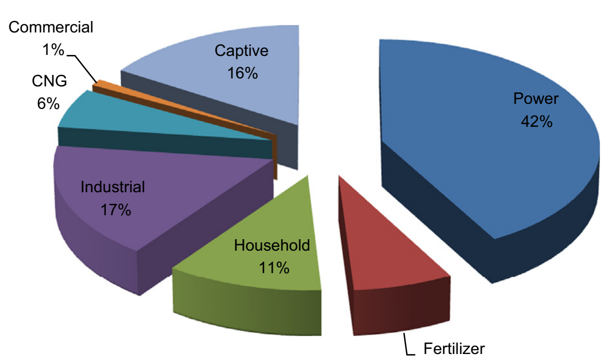


Fig. 2. Sectoral use of natural gas in Bangladesh [18].

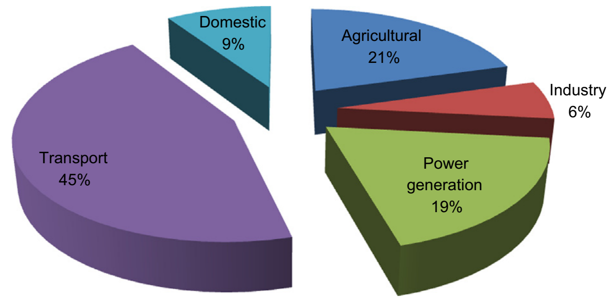


Fig. 3. Sectoral use of petroleum fuel in Bangladesh [18].

However, the government of Bangladesh recently has undertaken the Quick Rental Power Plant (QRPP) projects based on oil-dependent power plants. Rental power is a system that has been initiated and promoted by the government as an immediate measure to cope with the critical shortage of power. With the exception of several plants whose contract runs for a relatively long term of 15 years, most of the contracts are short term ones of three to five years in which the per unit cost of power inevitably becomes expensive as the rental power producer try to absorbed the depreciation of the plant within such short times. Thus, the QRPP was failed to achieve expected results due to the following reasons:

- The quick rental power initiative was adopted without required feasibility study and financial analysis.
- Government's budgetary control was failed to anticipate impacts of price increase of liquid fuel in international market.
- Bangladesh Power Development Board (BPDB) was obligated to purchase the rental power produced at such high cost and to sell the power at the regulated bulk tariff with no effective means to avoid the loss creating in the dealing operation. Consequently, all the power plants have miserably failed to commence production, as reported by Ali et al. [24]. According to the financial division [25], Bangladesh Petroleum Corporation (BPC) incurs a loss of about Taka 10.00 billion (1 USD = 80.5 Taka (Tk.)) in 2011–2012.Thus, the lack of proper energy management contributed to the huge amount of financial loss to national exchequer.
- Instead of qualifying developers through competitive bidding novice developers, mostly first timers were allowed to setup the power plants. Many of them failed to set up plants within time or even within several extended period.
- Most of the developers brought fuel inefficient second-hand equipments and machinery which generated much less than the rated capacity of power.

Thus, the failing of Quick Rental Plants is not only causing huge amount of financial loss to the national exchequer but also increasing the suffering of the citizen of the country. Therefore, it should have had a financial model and risks analysis carried out before jumping unguarded to contingency power plant actions. Government should have concentrated more in advancing implementation of large base load power plants and act more positively on replacing old fuel inefficient power plants with new modern plants.

Despite using oil as a fuel for power generation, the country has considered to use coal as substitutes for liquid based fuel due to declining production in recent years [26]. The government of Bangladesh has planned to build more coal-fired plants, as substantial amounts of coal reserves have been discovered in the north-western part of country [27]. The total amount of coal reserve is estimated at 1.756 billion t, in which the major estimated deposit from Jamalgonj (in the Jaipurhat district), Baropukuria (in the Dinajpur district) and

Khalashpir (in the Rangpur district). The estimated rate of coal extraction from Baropukuria is 1.0 million t/year, in which 70% will be used in a 250-MW coal-fired power plant [27–29]. Some regulations have been established to increase the share of coal in the future energy, especially for electricity generation purposes [30]. However, the main obstacle is Bangladesh's lack of a policy framework and financial mechanism [31].

3. Power generation and demand scenarios

Bangladesh is a growing economical country. The industrial sectors such as garments, medicines, leather have been developed over the last decade. Therefore, the actual demand could not be met during the last few years because of supply shortages caused by limited generation capacity [32,33]. Other key factors influencing energy demand are

- The demand for electricity has been rising due to the growth in population.
- Urbanization.
- The quality of life appears to have improved in the past few years.
- Access to electricity and mobile phones increased remarkably.
- The transportation-related energy demand was increased, mainly due to expanding economies and international trade.

Table 1
Overview of power sector in Bangladesh.
Source: Finance Division, Power and Energy Sector Road map: Second Update, 2012 data [18].

Installed capacity (de-rated)	8099 MW
Present demand	6000 MW
Present generation capacity	5200–6000 MW
Maximum generation (29 August, 2011)	6065 MW
Transmission Line (230 KV and 132 KV)	8996 km
Distribution line (33 KV and below)	2,78,220 km
Number of consumers	13.28 Million
Access to electricity	55.26%
Per capita power generation (including captive)	265 kWh

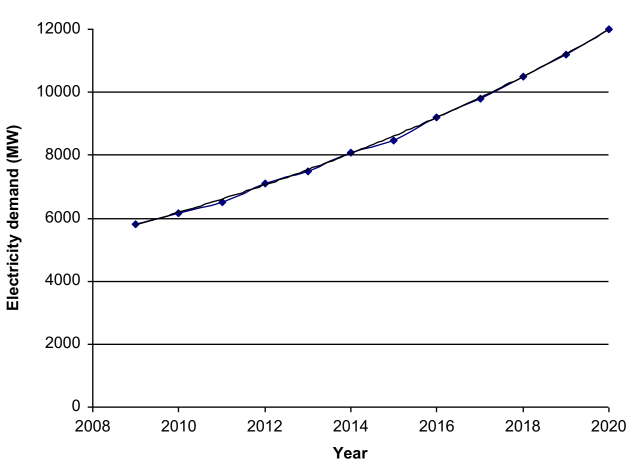


Fig. 4. The forecasted electricity demand upto 2020 in Bangladesh [34].

In 2011, power generation capacity was 4890 MW against the forecasted demand of 6765 MW which lead to significant amount of load shedding, often up to 1335 MW. However, the generation capacity has not kept up with even "new" connection loads resulting in demand and supply gaps and power outages. This situation can be further exacerbated because fuel supplies to power plants declined due to the increase of oil price [9].The total power production of the power sector in Bangladesh is furnished in Table 1.

It was reported by Shuvra et al. [34] that the future energy demand is expected to grow at a rate of 5–7% annually for the next 20 years from 2004, as can be seen from Fig. 4. Hence, to meet the demand with reasonable reliability, installed capacity must be increased to 12,000 MW. Otherwise, there should be power failures in the industrial as well as agricultural sector, which means food insecurity and less production. These in turn, will lead to lesser income; lessen capital formation, lesser exports and slow economic growth [35].

To meet the electricity demand, the forecasts for electricity production was incorporated to the Power System Master Plan based on the different GDP growth rates, as shown in Table 2. According to the plan, total 10,283 MW will be generated by fiscal year 2015. However, the difference between target and achievement was found to increase in last few years. Outwardly taken by it, the plan of the power sector in Bangladesh looks impressive, but it conceals many innate inadequacies of the system and its capacity to build up because of which it is lagging far behind the growing demand. A number of forces have been responsible for this plight which will be discussed in subsequent sections.

4. Policy and strategy perspective in energy sector

Looking at the present Bangladesh's energy demand scenario, power crisis has become an acute problem for the country. To improve the energy sector in Bangladesh through development of conventional and non-conventional energy, the government of Bangladesh has adopted a number of energy policies. There are many policy issues have been raised in last few years related to development of Bangladesh power sector. The policy options mainly focus diversification of energy supply mix, energy conservation and renewable energy development.

The National Energy Policy 1995 stressed the need for implementing energy efficiency but no steps were taken to implement even a single efficiency program for a decade. The National Energy Policy, 1996 which highlighted the participation of the private

Table 2
The power system master plan is based on three different demand scenarios.
Source: Finance Division, Second Update, 2012 [18].

FY	Government policy scenario		Comparison GDP 7% scenario		Comparison GDP 6% scenario	
	Peak demand [MW]	Generation [GWH]	Peak demand [MW]	Generation [GWH]	Peak demand [MW]	Generation [GWH]
2010	6454	33,922	6454	33,922	6454	33,922
2015	10,283	54,047	9019	47,404	8232	43,267
2020	17,304	90,950	13,244	69,610	10,868	57,122
2025	25,199	137,965	19,257	105,432	14,167	77,562
2030	33,708	191,933	28,537	162,490	18,828	107,207

sector in energy development and management program [36]. The policy guidelines for Small Power Plant (SPP) in Private Sector, 2000 stressed to the power generation and distribution for both national and foreign private investments [18,37]. The Bangladesh Energy Regulatory Commission Act, 2003 and Policy Guidelines for Power Purchase from Captive Power Plant, 2007 were stated the effective regulating and monitoring of the energy sector and sell the excess electricity to the electric utility [38,39]. In addition, the power division has also prepared a final draft of "Energy Conservation Act, 2009" for the improvement of energy to support private investment [40].

To improve supply of energy, a Power System Master Plan 2010 (PSMP) outlined a reform process focusing on infrastructural development, tariff rationalization, efficiency improvement, energy source and fuel diversification with a target to supply power to all citizens [25]. Recently, Sixth Five Year Plan and Vision 2021 has been introduced by the government to substantially increase power and other energy supplies, improve sectoral efficiency and increase energy trading activities with neighbors [25]. In addition, the following initiatives have been considered to reform the power sector that facilitate and attract investments, and to minimize energy demand [18,25,41–44].

- Increase of power generation to reduce demand-supply gap through public–private partnerships and through power imports from neighbors.
- Energy savings through demand side management i.e., shop closing times, staggering holidays in industries and shopping complexes, replacing "incandescent lamp" by compact fluorescent lamp (CFL)and reducing air conditioning load.
- Diversification of fuel use in electricity generation i.e., coal, liquid and other fuels and utilization of natural gas in fertilizer production.
- Provision for dual fuel in electricity generation wherever possible.
- Mobilization of funds for electricity generation projects through private sector participation.
- Reform energy sector to reduce cost and improve service delivery.
- Reduce system loss.
- Intensify exploration activities for finding new oil, gas and coal fields.

Electricity is the major source of power for country′s most of the economic activities. There have been a number of reforms in the power sector in Bangladesh over the past decade, but these reforms failed to bring desired demand in the power sector. The possible barrier in energy sector in Bangladesh will be discussed in subsequent sections.

4.1. Institutional and policy barriers

The power sector in Bangladesh is currently facing the challenge of how to simultaneously satisfy a growing electricity demand and meet the energy targets. The reform of decades-old power sector in Bangladesh is a major confront in which governments monopolized electricity generation. Power cuts are frequent, power supply is insufficient and irregular and high voltage fluctuations are common. These imbalances in the supply of power have been causing a lot of damage to the domestic, agricultural, and industrial sectors. Frequent fluctuations in power supply have been doing a lot of harm to valuable electrical equipment, electrical motors, electrical appliances, power stations etc. For want of constant power supply, agricultural and industrial productivity is being impeded. Alam et al. [6] in their discussion of the electricity distribution system in power sector of Bangladesh have emphasized the heavy system loss and poor collection performance with the power distribution system which regarded as the most pressing problem in the country. However, the government has given seldom priority to reform its distribution system.

Thus, it is hard to get benefits while leaving behind to reform its distribution system. It should be pointed out in this connection that, system loss in any power distribution system in Bangladesh should not exceed 10%, i.e., collection–import (CI) ratio should be kept above 90%, as reported by Alam et al. [6]. To maintain the system loss and the CI ratio at the recommended level, the malpractice by the utility personnel must be stopped fast. It was claimed by Ahmed [31] that the highly centralized bureaucratic system in Bangladesh is one the most important problem to develop energy sector. Therefore, all the decisions of the energy sector are taken at the top of the organizational hierarchy without consulting with the stakeholders. Thus, the employees cannot exchange their real problem in energy sector experienced with the field level. Governments should at least adopt a consultative approach in formulation of the reform plans which includes civil society and employees. Uddin and Taplin [30] have discussed on the sustainable energy development in Bangladesh and have reported that not only the organizational inefficiency causes the electricity crisis but also political interference, wrong policies, inadequate fund also responsible. Thus, the organizational inefficiency is actually shared between inefficiency of public organization and political interferences. All these problems are crippling the power sector and mitigating its financial strength (Fig. 9). Outwardly, taken by it, the growth of the power sector in Bangladesh looks impressive, but it conceals many innate inadequacies of the system and its capacity to build up because of which it is lagging far behind the growing demand.

4.2. Barriers related to demand side management energy conservation

The rate of energy efficiency improvement needs to be increased substantially to achieve a more secure and sustainable energy future. Further, gains in the efficiency of energy consumption will result in an effective reduction in the per unit price of energy services. [45].The implementation of technologies and practices which reduce energy consumption at the level of private and public organizations or individual households is often hindered by obstacles. Policy implications for the most relevant barriers in commerce and the services sector in achieving increased levels of energy efficiency,has been claimed by Schleichand Gruber [46], although Perez-Lombard [47] concluded from their work that the market for energy efficiency is not performing well due to the lack of information about the costs and benefits of energy efficiency. A similar conclusion has been reached by Dubin et al. [48] who studied the price effects of energy-efficient technology on residential demand for heating and cooling. Bangladesh is currently gaining experience with several energy efficiency projects, though these sustainability initiatives are at the initial stages of implementation. These viable approaches need to be amplified to a broader context with the formulation and implementation of a national energy efficiency strategy. Rather than reviewing the extensive literature on barriers [9,13,49,50], the barriers to implement energy efficiency (EE) in Bangladesh among others include

- Limited awareness of energy efficiency techniques and their economic benefits.
- Limited access to information and benchmarks for EE technologies.
- An unwillingness to incur what are perceived to be the "high-cost/high-risk" transaction.
- Preference for industries to focus on investments in production rather than on efficiency.
- Lack of financier interested to finance EE investments.

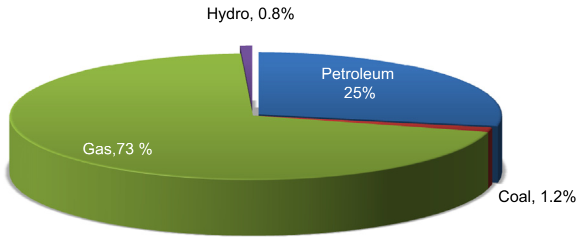


Fig. 5. Share of Total Primary Energy Supply [18].

- Insufficiently stringent regulations on EE standards and their implementation.
- Few EE technology demonstration projects by industry or government.
- Inadequate local energy support services and lack of trained industry and financial sector personnel in energy management.
- Energy users are often reluctant to try out innovative solutions unless they are confident that claimed benefits are achievable.

The generation of electricity in Bangladesh lies mainly on non-renewable sources. As can be seen from Fig. 5, around 73% of electricity generation is gas energy based, 25% of generation is petroleum product and 1.2% of electricity generation through coal based, while small contribution from hydro power is about 0.8% of the total installed capacity in Bangladesh. It was reported by Lior [51] that the limited reserves of coal, oil and natural gas may last only for 122, 42 and 60 years, respectively if the current rate of energy consumption is continued in the world. The shortage and constrained in availability of gas and petroleum fuel in Bangladesh, the government has to be directed towards the development of renewable energy in order to bring down the gap between demand and supply. Several researchers [52,53] have been reported the reasons to facilitate renewable energy.

(a) Harshening of renewable energy can be one of the strategic approaches to reduce the country's dependency on the oil exporting country.
(b) It can also provide greater reliability during times of high demand and pending blackouts.
(c) Renewable energy technologies facilitate the establishment of distributed generation which reduces transmission and distribution costs as well as system losses.
(d) Renewable energy technologies eliminate the need for the construction of new large-scale fossil fuel power plants and the associated economic risks that accompany these projects.
(e) Over all, it will reduce the risk associate with the climate change.

Given the energy challenges, and the disadvantages of non-renewable conventional energy resources, especially their negative impact towards the environment, Bangladesh government introduced policy measures for advancement of renewable sources [33]. Islam [32] reviewed the Draft National Energy Policy 2004 and Draft National Energy Policy 2006 to determine the barriers to the implementation of solar photovoltaic (PV) technologies in rural Bangladesh. It was recommended by Islam [32] that the government of Bangladesh need to bring changes in the planning methodology to incorporate a renewable energy development program under the framework of national energy policy. Renewable Energy Policy of Bangladesh, 2008 introduced to accelerate use of renewable energy through fiscal incentives, withdrawal of tax tariff for suppliers of renewable energy and institutional support through creation of Sustainable Energy Development Authority (SEDA) [54]. Though, SEDA is an advanced stage of enactment [55]. According to the policy on Renewable Energy adopted in 2008, the government target was to generate 5% total electricity using renewable energy technologies by 2015 and 10% by 2020. The upshot of the above observations is that evolving a sound energy policy and acting promptly on it is supremely important for the sustainable economic development of the country. Unfortunately the power situation in the country has not been satisfactory. Several initiatives have been taken by the government to promote renewable energy sector in the country.

5. Opportunities and barriers in renewable energy sector

Currently, there are about 40% of the total population in Bangladesh has access to electricity (Table 3), still without electric light and other amenities of the country. This situation is not likely to change soon due to the continuing growth of population. Off-grid solar PV systems such as solar PV-driven water pumping systems, small solar home systems (SHS), and small village grids are suited to greatly alleviate this situation (Fig. 6). While obviously superior to some forms of energy, solar power's high cost and efficiency dependent on geography (Table 4) have limited its appeal [22,56–58]. However, a large number of advantages also merit further development and even possible adaptation for residences. Solar energy remains popular because it is both a renewable and clean source of energy. These advantages along with the hope that eventually nations can use solar power to decrease global warming ensure its popularity. Thus, numbers of initiatives have been taken by the government to reduce country's energy crisis to some extent.

5.1. *500 MW solar project*

The government of Bangladesh has target to generate electricity about 500 MW from solar PV by 2015 [59,60]. It is estimated that USD 2.76 billion will be required to implement the 500 MW solar project. The government is seeking about USD 1.38 billion in the form of grants and USD 0.85 billion in the form of credits [61]. The financial mechanism of the project has been proposed by the Finance Division, Power and Energy Sector, Bangladesh (Table 5).

5.2. *Commercial and small-scale solar power projects*

5.2.1. *Solar home system*

The major portion of total population in Bangladesh still does not have access to electricity. Only 10% of the rural households have electricity connection and there are some parts of Bangladesh which will not get the access of electricity connection from the national grid within next 30 years [62]. In areas too remote to be connected to the electric system, solar power and photovoltaic cells are being used to light up homes [63]. Several studies have been reported on solar home systems in Bangladesh [64–66]. Bhuiyan et al. [67] studied on the economic analysis of the home

Table 3
Category wise consumer statistics of electricity sector in Bangladesh.
Source: Finance Division, Second Update, 2012 [18].

Use	Amount
Domestic	11,103,509
Irrigation	229,029
Commercial	1,434,025
Industry	416,740
Others	33,283
Total	13,281,586



Fig. 6. Application of solar PV system in Bangladesh.

Table 4
Overview of potentials and limitations of PV system.

Area	Potential	Limitation	Result
Equipment and investment	Flexibility: Easy scaling from a few Wp upward	High investment cost per (Wp)	PV mainly competitive in low energy use range in remote, unelectified areas Need for financing mechanisms (also due to low capital availability in rural areas)
Operations and maintenance	Reliability: Low maintenance and supervision needs and costs	Need for back-up or storage for use at night and in days of low insulations. Battery is weak of PV system.	PV system often competitive on life cycle cost basis
Organization	Easy integration in user package adapted to users′ needs	Higher involvement for user necessary for PV projects more than for grid extension projects	Need for institutional changes in the energy sector for PV rural electrification projects
Environmental implications	Environmentally friendly: Low emission of CO_2, and other emissions compared to fossil fuels based system	Disposal of battery is the major environmental issue	Possible financing from climate change fund

Table 5
Financing mechanism of solar projects in Bangladesh.
Source: Finance Division, Second Update, 2012 data [18].

	Projects	Estimated capacity (MW)	Estimated investment required (Millon USD)	Estimated grant (Millon USD)	Estimated equity (Millon USD)
Commercial projects	Solar irrigation pumps	150	806	506 (50%)	160 (20%)
	Solar power minigrid system	25	168	85 (50%)	33 (20%)
	Solar park at government land	115	546	–	164 (30%)
	Solar park at railway land	20	95	–	28.5 (30%)
	Solar power in private, commercial and residential buildings	10	52	–	16 (30%)
	Solar power in industries	20	104	–	31 (30%)
	Subtotal	340 MW	1771	491	432.5 (24%)
Social projects	Solar electrification in rural health centre	50	310	279 (90%)	31 (10%)
	Solar electrification in remote educational institute	40	246	221 (90%)	25 (10%)
	Solar electrification at union E centers	7	44	40 (90%)	4 (10%)
	Solar home system in religious establishment	12	75	67.5 (90%)	7.5 (10%)
	Solar electrification at remote railways stations	10	62	56 (90%)	6 (10%)
	Solar power system in Government/semi government offices	41	254	229 (90%)	25 (10%)
	Subtotal	160 MW	991	892.5 (90%)	98.5 (910%)

system in Bangladesh and reported that life cycle cost of PV energy is lower than the cost of energy from diesel or petrol generators in Bangladesh. Nfah et al. [68] who reported that that off-grid options based on renewable energy resources could be a suitable alternative for rural electrification in the low power range (10–50 kW). Thus, it can be inferred that the PV generator is economically feasible in remote and rural areas of Bangladesh. It was reported by Sadrul Islam et al. [14] that more than 1.3 million households have been connected SHS which is expected to be increased to 3.8 million by 2014.

5.2.2. Replacement of diesel irrigation pumps with solar PV

According to the power division of Bangladesh [18], there are about 1 million t of imported diesel fuel is required for 1.34 Million diesel operated pumps in every year. Considering the crisis in the electricity sector, the government has given priority in solar power to explore alternative energy sources for irrigation. In Bangladesh, the average solar radiation is 3.85 kWh/m^2/year, which can be supplied energy required for irrigation during the monsoon [69,70]. It was reported that 150 MW of solar power is required to replace the 18,700 diesel pumps [25]. However, it can be recommended that the proper installation and smooth operation of the plants need to be ensured by the government through periodic inspection.

5.2.3. Solar mini-grid power system at remote villages

Electricity accessibility in remote areas is a challenge since the grid cannot be expanded. **S**asithranuwat and Rakvichian [71] designed a mini-grid for isolated offices and Vandenbergh et al. [72] presented the operational experience in mini-grids of two pilot plants based on the AC coupled PV technology in the Austrian Alps and in an remote area on the Greek island of Kythnos. Both systems are operated with satisfactory performance. Similarly, Nandi et al. [73] reported that the solar mini grid connection is more economically preferable than the stand alone system. However, the cost of solar mini grid depends on the several factors, such as, village topologies, load profiles, site dependent time series data for wind speeds or water flow. Moreover, optimal sizing of the components and optimal operational control strategies are important in designing and operational management of a Solar Mini Grid Power System at Remote villages [74].

5.2.4. Solar parks

Solar photovoltaic cells convert sunlight into electricity and many solar photovoltaic power stations have been built, mainly in Europe. As of October 2009, the largest solar PV power plants in the world are the Sarnia Photovoltaic Power Plant (Canada, 80 MW), Olmedilla Photovoltaic Park (Spain, 60 MW), the Strasskirchen Solar Park (Germany, 54 MW), the Lieberose Photovoltaic Park (Germany, 53 MW), the Puertollano Photovoltaic Park (Spain, 50 MW), the Moura Photovoltaic Power Station (Portugal, 46 MW), and the Waldpolenz Solar Park (Germany, 40 MW) (PV Resources.com (2009)). Some photovoltaic power stations which are presently proposed will have a capacity of 150 MW or more [75]. Recently, Bangladesh has taken initiatives which will have capacity of 135 MW [76,77]. According to Finance division, unutilized government and railway lands have been targeted to use for solar parks in the country.

5.2.5. Roof-top solar power solution for commercial and residential buildings

Today, typically roof-top, building integrated roof or façade PV systems are embedded in industry—political programs like the 100,000-roof program of Germany, the 70,000-roof program of Japan, and the million solar roofs initiative of the United States [78].Bangladesh government has a directive to install solar panel to meet certain percentage of load demand as a pre-condition to get new electricity connection. The total roof-top Solar Power, as reported by Finance division, was 10 MW, in which 3 MW Solar Panel already installed throughout the country, as of June 2011. A number of researchers [78–82] have identified the factors influencing the roof-top solar power. It was reported that balanced panel tilt, panel spacing, system shading, and system mounting technology need to consider generating high total energy production from limited roof space.

5.2.6. Installation of roof-top solar solutions at industries

Government has taken initiatives to encourage industries to install solar panel to meet certain percentage of their load demand from solar power. According to the Finance division, 400 industries have been identified which required 20 MW and estimated solar power generation capacity of 20 MW. However, it would be crucial for the government to implement the facilitation of the installation of roof top solar solutions at industries.

5.3. Solar power projects in remote establishment

In remote areas, new technologies for off-grid rural electrification promise environmentally benign access to electricity at a lower cost than conventional technologies. In particular, the following social development impacts may be expected: electric lighting (up to 200 times brighter than kerosene lamps) [83,84] directly improves the quality of life—it allows children to study in the evening and women to gain some precious time for themselves or to extend income generating work into the evening hours [85–87]. Residential and public light increases safety—again, children and women profit most [88]. Money for conventional fuels can partially be saved and then be spent by households on social purposes [89,90]. Access to means of modern communication and information reduces the marginalization of rural residents (horizontal inequality). Public centers may profit highly from this access. TV, light or productive uses in community centers enhance social life and may facilitate community based development.

5.3.1. Solar electrification of health centers

Most of health centers in Bangladesh are not connected to the grid. Electricity requires to conduct minor surgeries or even to preserve vaccines and medicines in these centers. The estimated rural community center only in remote villages was 18,000 which required 50 MW of electricity [18]. However, the delivery of quality medical services to the rural people depends on the successful implementation solar projects where grid is not available.

5.3.2. Solar electrification in remote educational institutes

It is promising that some “Off Grid” educational infrastructures with renewable energy technology (RET) are successfully running in some remote areas. But more areas should be covered to apply RET and develop sustainable educational system in Bangladesh. Government has selected remote government and non-governmental educational institutions to provide solar power systems, as many of the remote school do not have either dependable electricity supply or even grid electricity access. Successful exertion of solar projects can bring the following benefits [91].

(a) The modern technological advancements in education can be uplifted.
(b) Schools may provide better learning conditions.
(c) Distance learning approaches based on computer or TV can open a wide range of education improvements.

5.3.3. Solar electrification at union E-centers

Many of the union centers, the lowest administrative unit of government, in Bangladesh do not have electricity supply. The estimated numbers of union centers are 4501 which required 7 MW of solar power, as reported by Finance division [25]. The remote villagers can be accessed information through the installation of solar PV systems in Union Centers.

5.3.4. Installation of SHS in religious establishments

Most of the religious establishments like mosques, temples, pagodas are operated through government and public support. However, very few have grid electricity connection in remote areas. Thus, the initiatives have been taken by the government to install the solar home system in religious establishments. However, proper maintains has to be ensure of such project to get the maximum output.

5.3.5. Solar electrification at remote railway stations

There are about 450 Railway station in Bangladesh, many of them are located at remote areas. Thus, Solar PV with battery backup supply may be ensured reliable electricity access to those railway stations.

5.3.6. Solar PV system in government and semi-government offices

Different government administrative offices, NGO offices, health centers, schools, banks and police stations are functioning throughout the country. These offices are using either traditional means (lantern, candles, kerosene wick lamps etc.) or operating their own diesel generator for lighting. Government has taken initiatives to install solar PV systems in their buildings within the next 3 years [14]. Thus, the certain percentage of their electricity load can be met from PV solar.



Fig. 7. Cooker used by villagers in Bangladesh: (a) traditional cooker; (b) cooker developed by Bangladesh Council of Scientific and Industrial Research (BCSIR).

5.4. Incorporation of biomass and biogas-based technology for villagers

Biomass plays an important role in the country's energy consumption especially in the rural areas where it is used extensively for cooking. A large number of country peopleutilizes traditional cooker, using various mixtures of solid fuels such as biomass, coal, animal dung, crop residues, typically rice straw and dried leaves. Thus, the indoor air pollution from biomass fuels and traditional cooking stoves may be a serious health threat, particularly to women and young children who spend a considerable amount of time near the cooking stove [92]. According to the World Health Organization (WHO), 32,000 children and 14,000 women die each year as a result of indoor air pollution [93]. Dasgupta et al. [94] studied on the emission of particulate matter (PM) from traditional cooker in Narayanganj District of Bangladesh and reported that the particulate matter (PM) with aerodynamic diameter less than or equal to 10 μm in diameter emit from the traditional cooker. Consequently, the particulate matter emitted from the traditional fuels is considered a major risk factor for lung cancer as well as cardiovascular and respiratory disease [93]. A similar conclusion has been reached by Chowdhury et al. [95] who studied the effect of particulate matter emitted from traditional cooking stoves on human health.

Upon realizing the situation, the Deutsche Gesellschaftfür Technische Zusammenarbeit (GTZ), the German development organization, and Grameen Shakti have given effort to developed improved gas stoves aiming to improve fuel efficiency and to reduce indoor air pollution levels [96]. However, successful result has not been come out. In these circumstances, the Bangladesh Council of Scientific and Industrial Research (BCSIR) developed cook stoves (Fig. 7) that burn fuel more efficiently and cause significantly less smoke and pollution in the kitchen [96]. The special features of improved cook stoves, as reported by financial division, Bangladesh [25] are as follows:

- significantly reduces the amount of firewood consumed (up to 50%);
- reduce expenditure for rural households for buying firewood;
- keeps kitchen areas clean, and free of smoke and pollutants;
- significantly reduces the incidents of indoor smoke related illnesses and deaths;
- reduces the risks of accidents in the kitchen; and
- contributes to reduction in greenhouse gas emissions.

Further, it was confirmed by Chowdhury et al. [95] that the cooking with the BCSIR improved stove in Bangladesh instead of the unimproved mud stove lowered CO and PM2.5 concentrations by 23% and 59%, respectively. GIZ has attempted first to disseminate the improved gas stove. The objective was to introduce the technology in rural households, institutions and commercial establishments to reduce the pressure on bio mass consumption and mitigate against indoor pollution. According to Rapid Assessment Gap Analysis Bangladesh Draft report [25], the total number of 450,000 improved cook stoves have been installed throughout the country. However, the maintenance of cooker is crucial in order to ensure the quality and durability of the improved gas stovesunder appropriate environmental safeguards.

Attention in biogas technology is growing in Bangladesh because of the increasing awareness of the importance of the renewable energy sources and their potential role in decentralized energy generation. Realization of the importance of biogas

technology to supplement the energy sources in the rural areas of country, BCSIR initiated to disseminate the domestic biogas in rural areas with the ultimate goal to establish a sustainable and commercial biogas sector in the country. In addition, several government agencies and NGOs have given effort to disperse the technology throughout the country. According to Finance division [18], 50,000 biogas plants have been constructed throughout the country, as of 2007. Further, IDCOL, Netherlands Development Organization (SNV) and German Development Bank (Kfw) and Government of Bangladesh were continued this program to implement rural areas in the country. However, Succession and perpetuation are major issues for this project as improper maintenance may deteriorate the efficiency of the biogas plant.

Besides, feasibility study of pyrolysis for production of alternative liquid fuel from organic solid wastes (scrape tyre, waste plastic, municipal solid wastes and lignocellulosic materials) may be carried out in Bangladesh. As for bio-fuel, a joint venture between a local company (NITOL MOTORS) and two Singapore firms have recently been signed to invest USD 4.5 million to manufacture 12,000 l of ethanol from molasses from the Sugar Mills of North Bengal. It will be mixed with normal petrol/octane in the ratio of 23:77 to be produce "gasohol" to run motor vehicles. The price of "gasohol" will be 20–30% lower than conventional petrol [10].

The tannery waste can be another source of "Biofuel" production in Bangladesh. Processing of hides and skins for leather as a finished product has long been an important industrial activity. As per reviewing the data from several studies [97–102], processing of 1 metric t of raw hide produces on an average 200 kg of tanned leather, 200 kg tanned waste leather, 250 kg of non-tanned waste, and 50,000 kg of waste water. Consequently, the tannery waste is generating toxic chemicals and waste which have extremely harmful effect for both of man and animal. It may be mentioned that about 12 sq km area of Hazaribag and its adjacent area are full of offensive odors of various toxic chemicals like hydrogen sulfide, ammonia, poisonous chlorine and several nitrogen based gases. It was reported that the ground water in the entire Ranipet, Ambur and Vellore regions is contaminated due to the presence of toxic materials in the solid waste from the tanneries [103]. Thus, the tremendous environment pollution and biological chains destruction causing negative environmental impact has been regarded as an inevitable consequence of tannery waste [35]. Realizing this situation, the government has given special emphasis to relocate the tanneries from the Hazaribagh area of Dhaka cities to minimize the environmental pollution and make the city more habitable. However, only the relocation of the industry cannot solve the problem associated with tanneries. Without adapting eco-friendly with sustainable technology for the tannery waste, it seems that the pollution occurred by tannery industry is only transferring from one place to another within the country.

The poultry feeds are recently being prepared by using poisonous tannery waste in Bangladesh. Leather tanning industry uses many types of harmful chemicals which, when they react each other, release hazardous chemicals like zinc, cadmium, chromium and arsenic and also emit offensive smells due to hydrogen sulfide [104]. These chemicals are passing through the feeds into the chicken meat and eggs. Innocent peoples of different ages group of the country are regularly consuming those chicken and eggs and suffering from various complex diseases. It was reported that the toxicity of cadmium, chromium important determinants in lung cancer development [105].Therefore, immediate measures must be taken to stop preparing poultry feed using such poisonous tannery waste to protect human health of Bangladesh.

Kolomaznik et al. [106] evaluated the leather industry tannery wastes for biodiesel production and reported that the relatively simple treatment of untanned leather waste may provide a practical and economical solution to the disposal of potentially difficult waste. It may be mentioned that the tannery wastes containing protein and fat that constitute more than 40% of raw hide are regularly disposed to the environment [106]. It has already been proved [107,108] that the contaminated waste can be utilized in the production of an environmentally friendly fuel that can ultimately be used in every engine working with petrodiesel without adapting a major adjustment and changes, which provides the substantial economical and ecological profits [107]. However, the potential profit from the utilization of low cost tannery fat wastes for biodiesel production depends on the processing costs of the pre-treatment technology; which includes their refining and esterification of free fatty acids [106]. Thus, the waste fat produced by tanneries during the processing of hide and skin can be used as a raw material for biofuel production which can save the country from poisonous toxic chemicals as well as severe environmental pollution. Accordingly, the leather industry of Bangladesh will be highly prosperous with eco-friendly and sustainable industry in future, if the government extends their helping hand to set up every tannery industry with biofuel plant.

Waste cooking oil can also be cheap another source for biofuel production in Bangladesh. In most cases, waste oil is being used at restaurants for cooking and process of food. The number of times of re-use of cooking oil could have significant impact on human health. Several studies clearly stated that a toxin called 4-hydroxy-trans-2-nonenal (HNE) forms when cooking oil is being reused several times [109,110]. Consumption of foods containing HNE from cooking oils has been associated with increased risks of cardiovascular disease, stroke, Parkinson's disease, Alzheimer's disease, Huntington's disease, various liver disorders, and cancer as well. Once absorbed in the body, HNE reacts with DNA, RNA and proteins affecting basic cellular processes. The risk of hypertension is positively and independently merely associated with the intake of negatively cooking oil polar compounds and inversely miserably related to blood concentrations of monounsaturated fatty acids [111–113]. Therefore, biofuel production from the waste cooking oil could be suitable alternative to avoid their adverse effect on human health and environment. Moreover, policies need to be formulated that targets the climate change mitigation and adaptation, energy security and economic development in Bangladesh.

5.5. Wind energy

Numerous research studies have been conducted to investigate the conceivability of wind energy in Bangladesh. The remote coastal inlands and islands in Bangladesh are potential for wind energy, has been reported by Azad [114]. Bangladesh Centre for Advanced Studies (BCAS) investigated the wind speed for costal locations at 25 m height in Bangladesh in 1996–1997 [115]. It was reported that the average wind speed in coastal belt is 5 m/s [115], corresponding to a theoretical power production between 1000 and 3000 kWh/(m^2 year) [116]. Similarly, the German Organization (GTZ) studied the wind speed for different coastal locations in Bangladesh at a height of 20 m in 1999–2001 [115] who concluded that the highest wind speed (5.12 m/s) was found during summer at Kutubdia and Kuakata. A somewhat related conclusion has been reached by other researchers [117,118] who studied the feasibility of wind energy at Kutubdia Island, Bangladesh. Recently, Nandi et al. [115] have evaluated the wind speed and direction at different location near the coastal belt in Bangladesh (Fig. 8). It was reported that the coastal regions in Bangladesh are potentially applicable for wind energy. However, the cyclones and norwesters may cause problem for wind machine during monsoon period (March–October) due to its exceeding design parameters. Thus, the design parameters of the windmill should be addressed before installing the wind machine. The wind speed persistence and wind power density are critical to all aspects of wind energy

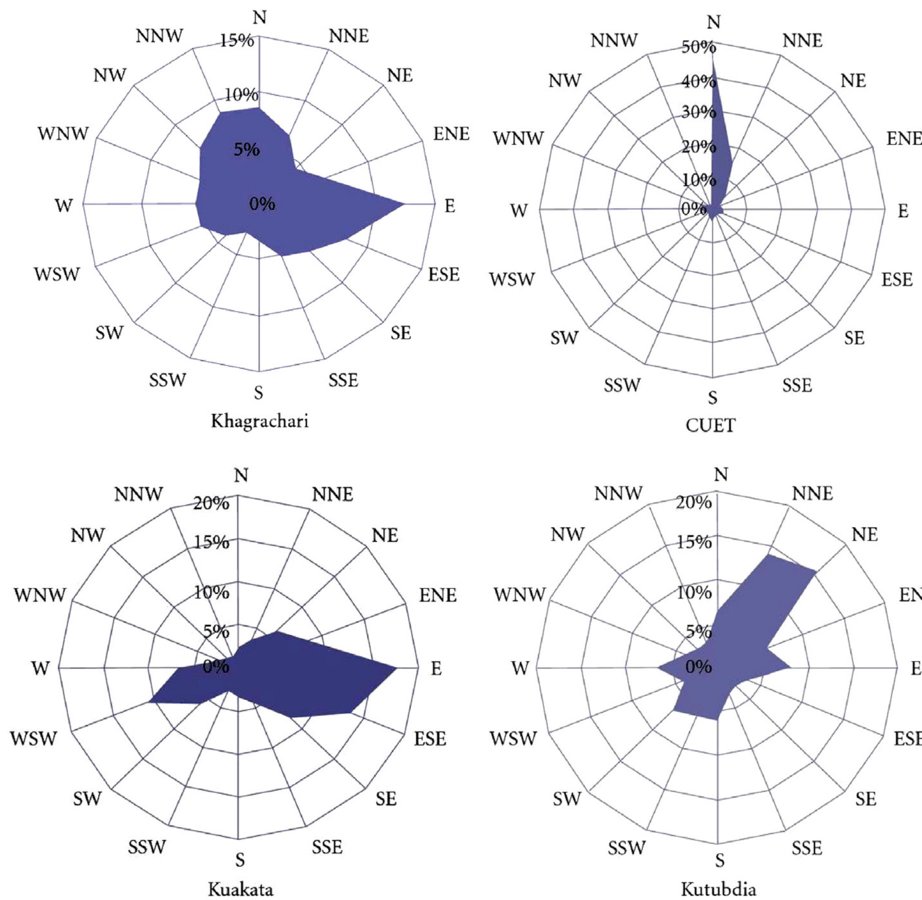


Fig. 8. Wind rose for different locations showing percentage of wind direction [109].

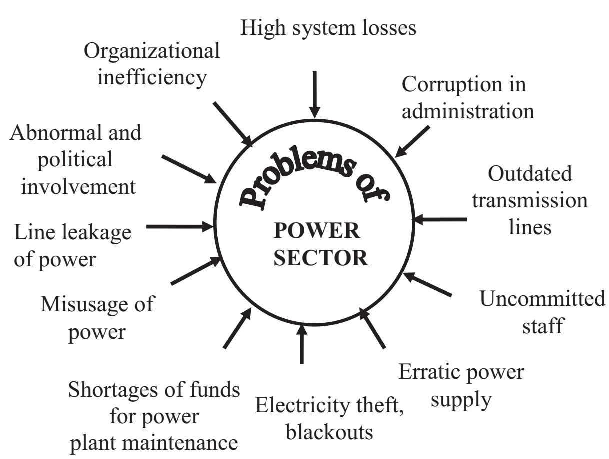


Fig. 9. Problems in power sector of Bangladesh.

exploitation, from the identification of suitable sites and predictions of the economic viability of wind farm projects [119,115]. Further, it was recommended by Mondal et al. [7] that the NASA-SSE data set can be used to develop a wind map of Bangladesh to determine potential sites for wind energy exploration. Thus, the study of geographical distribution of wind speeds, characteristic parameters of the wind, topography and local wind flow and measurement of the wind speed are very essential in wind resource assessment for successful application of wind turbines. Presently, there are 1.9 MW of installed wind turbines operating in Bangladesh, notably at Feni and Kutubdia [21].

5.6. Initiative to build nuclear power plants

The rise of global warming concerns throughout the world over the last ten years has led to a renewed interest in nuclear energy. As the price of oil and global warming concerns both continue to raise steadily, a renewed interest in the clean-burning properties of nuclear power are becoming much more attractive. However, the safety of nuclear power plants has become the concern of the hour. Thus, the question naturally arises, nuclear power renaissance in Bangladesh—why now?

Let us review the disaster of nuclear plants before arriving at any conclusion. Till date, three major nuclear accidents have been occurred namely, the Three Mile Island accident, the Chernobyl disaster and the recent happenings at Fukushima nuclear station. The accident at the Three Mile Island was the most serious in U.S. commercial nuclear power plant operating history, even though it led to no deaths or injuries to plant workers or members of the nearby community. But it brought about sweeping changes involving emergency response planning to tighten and heighten its regulatory oversight [120]. The Chernobyl disaster was a result of the operation in unstable operating regimes, which has now been banned [121]. Today's nuclear reactors are designed specifically to avoid that unstable condition. Lastly, the Fukushima disaster was as a result of rare twin attack of nature as both an earthquake as well as a Tsunami [122]. Fukushima reactor is situated at the seismic seduction zone where two plates namely Japan plate and American plate always find place for intrusion. Japanese scientists prepared the reactor in such a way that it can resistant earthquakes. But the scientist ignored the Tsunami like situation triggered by earthquakes. Therefore, the tsunami water disabled the generator system which gives the power to nuclear reactors.

However, the proposed nuclear plant in Bangladesh is situated in less prone to the earthquake or tsunami. The investigations for the Rooppur Nuclear Power Plant, mainly in the areas of hydrology, morphological analysis, subsoil investigation, seismic studies and radiological dispersion studies have been carried out as per International Atomic Energy Agency (IAEA) recommendations. The study clearly identified nuclear option as appropriate and viable for Bangladesh. Recently, Bangladesh has agreed to build two new nuclear power plants at Rooppur in Pabna with Russian help as the country looks to close a yawning power deficit [123]. Under the agreement, Russia will construct two 1000 MWe reactors at Rooppur, in Pabna district. Russia will also support Bangladesh in developing the necessary infrastructure for the proposed plant.

Primary energy resources are insufficient for bulk production of electricity to meet present and future consumer demands in fast growing industrialization of the country. All the developed countries of the world are producing bulk electricity power through pollution free nuclear power plants for the bulk consumer demands in addition to traditional sources of energy available in their countries. Therefore, nuclear energy is the only the option for the country at this energy crisis situation to support the enormous spike of demand. It was reported that that Compared to coal at USD.0145, oil at USD.0241, and natural gas at USD.0284 per kilowatt hour, nuclear power is a bargain [124]. In addition, several factors seem to be driving the resurgence of interest in nuclear power as proposed by Adamantiades et al. [121].

- A global desire to diversify fuel sources, reduce dependence on fossil fuel imports, and develop immunity to power disruptions.
- A desire to mitigate volatile fuel costs, given the low dependence of the price of nuclear-produced kilowatt-hours on the price of uranium.
- The need to mitigate climate change by reducing greenhouse gas emissions—specifically, carbon dioxide.
- A desire to decrease air pollution, by taking advantage of the virtual absence of air pollutants from nuclear plants.
- A way to prepare the transition towards a hydrogen economy.

However, nuclear safety, disposal of radioactive wastes, and proliferation of nuclear explosives need to be addressed in an effective and credible way if the necessary public support is to be obtained. By extensive use of other renewable energy, it could definitely be reduced the use of nuclear energy over a period of time. Thus, the nuclear energy should be minimized by maximizing the use of renewable energy.

Renewable energy has the potential to play an important role in providing energy with sustainability in developing countries. Although economically viable for several applications, renewable energy has not been able to reach its acceptable limit due to several barriers to its penetration. Thus, the transition of energy from non-sustainable to renewable is the major challenge of the first half of the 21st century. However, a more general aspect of the adaptation of a new technology is the need to build up a new infrastructure for dissemination of distribution, installation and information. It has been claimed by Owen [125] that the strong dependency of power generated from non-renewable resources is one of the main barrier to stimulate the renewable energy technologies, although other researcher [126,127] concluded from their work that short-term strategies in country's renewable energy sector constraint its expansion. Dincer [128] reported that the hurdles in dissemination of renewable energy due to the lack of awareness on the negative environmental impact created by the combustion of fossil fuel. May be mentioned in this regards that the combustion of fossil fuel emits benzene, toluene, ethylbenzene and xylene isomers (BTEX) which are vigorously toxins for human body [129]. Verbruggen et al. [130] in their discussions of the barrier of Renewable energy have emphasized on the lack of improved economics with full-cost pricing attaining spatial and temporal efficiency and bad governance of a country. Further, Wohlgemuth and Madlener [131] reported that the direct and indirect subsidies in power sector generated by fossil fuel obstacle the propagation of RET access in rural areas, but more recently, the barrier to the diffusion of renewable energy have been studied by Negro et al. [132] and concluded that the poorly implementation of incentive mechanisms like feed-in tariffs reduce the diversity of renewable energy access. Other crucial aspects as considered by several researchers [130,133–135] may be summarized in the following points:

- Technical barriers: lack of familiarity with RE and lack of promotion.
- Financing barriers: high initial costs of RE and lack of finance mechanisms.
- Institutional barriers: regulations, monopolies, import tariffs, subsidies, quality standards.
- Market barriers: lack of sufficient market base to warrant private investment; and lack of local infrastructure for installation and maintenance (increasing cost and lowering reliability).
- Lack of political commitment and adequate policies.

Apart from the above, lack of the mobilization of finance, innovative financing mechanisms are the hurdle toward a sustainable energy future for Bangladesh.

6. Approaches to overcome barriers and to minimize energy crises

The government has the challenge of expanding access to affordable, reliable and adequate energy supplies as a way to address economic development. In fact, power has become important and indispensable practically in every sphere of activity. Thus, in order to address an increasing demand, the following aspects need to consider in energy sector.

6.1. Approach to overcome barriers in power sector

The important factor affecting adversely power production in Bangladesh is the distribution system, which is characterized by heavy system loss and poor collection performance [6]. However, the government has given seldom priority to reform its distribution system. Alam et al. [6] acknowledged that the reformation of power distribution system and restructure of its administration were believed to make the energy sector efficient and effective. However, it will be difficult to derive benefits from the reforms while leaving the distribution system untouched. Another important factor affecting adversely power production is the uncertainty about performance indicators, which seem uncontrollable. Over the past decades, long-running inefficiencies in energy sector associated with the performance indicators which should be monitored continually to maintain the system loss [6]. It was reported that both the system loss and the collection–import ratio should be maintained at a recommended level [136]. In addition, the power supply system in Bangladesh remains inadequate due to inefficient poor commercial utility practices. Key recommendations to overcome crisis in electric power sector, as proposed by several researcher [44,137–140] will be described in the following sections.

6.1.1. Reformation of power distribution system

The government should plan properly to meet the demand for power on a long-time basis. Therefore, maintaining a proper balance should be the main task of the power authority. It is the responsibility of the distribution authorities to plan properly to have a foolproof transmission system, free from leakage, wastage, pilfering etc. It was reported by Alam et al. [6] that if the power distribution sector could perform at the expected level, a saving of about Tk. 200,000.00 million could be generated in a decade from the recovery of non-technical losses. In addition, about Tk 60,000.00 million could be recovered from collection of the unrealized bills. Thus, the government, in order to avoid energy crisis, should acknowledge to mobilize funds for the power sector in Bangladesh, particularly for the schemes relating to reform the distribution system.

6.1.2. Reducing system loss

The power distribution efficiency should be improved with an appropriate new technology. Thus, leakages and wastages have to be prevented at all costs. Faulty lines have to be replaced by new transmission lines with fully concealed and distribution centers. It is recommended to erect the total concealed power lines and substations to transmit power without any undue loss in power distribution. Further, all substations should be strengthened and restructured to transmit the power without any loss to the consumers. The government should have plan for long-term development of the distribution system, to give satisfactory service to consumers of all categories. It would be wisdom to plan a long-term power generation strategy to enhance power generation efficiency.

6.1.3. Recommendation to use energy efficient home and office appliance

Spurious or substandard ones have to be replaced by genuine and efficient ones. As reported by Das et al. [44], the use energy efficient home and office appliance can prevent frequent power cuts, fluctuations of voltage etc. A new strategy should be adopted to use the energy efficient appliance at home and office.

6.1.4. Control misuse and corruption in power sector

Severe energy crisis gets even worse in Bangladesh due to unscrupulous thieving of power, the theft of power, illegal and unauthorized use of power which should be stopped at all costs. It may be mentioned that the corruption is rampant in Bangladesh in almost every sphere of life. According to the Berlin based international organization Transparency International (TI) showed that Bangladesh was at the bottom for five years (2001–2005) in the annual corruption perception index (CPI). However, in the following six years it improved slightly. From 2006 to 2011, it ranked third, seventh, 10th, 13th, 12th and 13th respectively [141–143]. A mechanism for vigilance and control of malpractices has to be set up and made to function properly. A separate act should be enacted to control and punish the culprits in the misuse of power. As power is very vital, culprits and trespassers have to be dealt with promptly and without compunction. The studied on the power sector reform in Bangladesh has been performed by Alam et al. [6] who recommended from their work that the utility personnel who living on fraudulent income should be listed and be made liable to punishment under the provisions of 4 and 5 of the Anti-Corruption Act 1957. Under these provisions, a person having any property in his/her possession either in his/her own name or in the name of any other person on his/her behalf, which there is a reason to believe to have been acquired by improper means and is proved to be disproportionate to his/her known resources of income, shall be punished with imprisonment for a period up to 7 years and with a fine. On such condition, that disproportionate property of the accused shall be forfeited to the Government. Further, the similar research group [6] has been proposed that the utility personnel who are involved in the pilferage of electricity should be punished along with the corrupt consumers under the provisions of section 39, 40, 44, 46 and 49 of the Electricity Act 1910, as amended by Act 9 of 1993. According to these provisions, the liable person shall be punished with imprisonment for a period up to 5 years.

Beyond these above steps, based on the issues highlighted, some recommendations proposed by several researchers [7,44,138,139] for possible actions at power sector in Bangladesh as follows: (a) improvement of load situation through demand side management; (b) shifting load to off-peak; (c) large scale use of prepaid meter; (d) observing energy week; (e) proper load management. Overall, the report recommends better monitoring and regulation of operations, improved regulation of access to natural resources by investors, and increased stakeholder involvement in the energy sector. It calls for the government to recognize the role that improved energy supply can play in poverty reduction by designing sustainable energy policies.

6.2. Approach to boost up efficiency in energy sector

The growing trend in building energy consumption will continue during the coming years due to the expansion of economic activities. Consequently, it is important to mention that energy policy must improve the economic framework for more efficient energy use. However, several efforts, such as the distribution of 10.5 million energy efficient compact fluorescent lamp (CFL) bulbs, use of CFL bulbs in all ministries and power sector entities; replacing conventional street lights by light-emitting diode (LED) lights and solar powered systems have been made to increase energy efficiency. Further, based on the issue highlighted, some recommendations proposed by several researchers [35,144,145] for possible action to enhance the efficiency in energy sector are listed in the followings.

- Building awareness among children by introducing Energy Efficiency issues in the curricula of schools, madrasas and colleges.
- A common platform of the government and other stakeholders, including businesses, investors, NGOs and academia can be made to boost up energy efficiency sector in the country.
- A media campaign to increase awareness about the benefit of energy efficiency.
- Strong monitoring and maintaining authority can be built up to raise the energy efficiency.
- Information on Energy Efficiency has been disseminated through the mass media, newspapers, conferences, seminars, workshops and publication.
- Bangladesh government has to create an environment so that donor agencies and private investors take interest to mobilize their funds and invest in energy efficiency sector.

Private initiative together with government intervention through the promotion of energy efficiency, new technologies for energy production, limiting energy consumption and raising social awareness on the rational use of energy will be essential to make possible a sustainable energy future. In summary, initiatives should be taken to bring about comprehensive reforms in the power sector to facilitate and attract investments and bring about improvements in the efficiency of delivery systems.

6.3. Approach to overcome barriers in renewable energy sector

The shortages and constraints in availability of fossil fuels support for enhancing the deployment of renewable energies. Creagh [146] recently reported that energy production must shift from fossil fuels to renewable sources within four decades to avoid the most damaging consequences of climate change. The following strategic approach can be made in renewable energy sector to satisfy the country's growing energy demand.

6.3.1. General policy to promote renewable technology [10,78,147,148]

Establish a consistent and comprehensive framework for monitoring renewable energy production and consumption in the country.

- Create a common and coordinated strategy for introducing renewables into the country.
- Internalize the macroeconomic policy into energy markets.
- Establish consistent, long-term policies and incentives for renewable energy.
- Domestic rules and regulations to be consistent and supportive of renewable energy.
- Defined decline of feed-in tariff rate and price level of system.

6.3.2. Incentives for renewable energy [10,133]

- Promote renewable energy by excluding sales and property taxes assessment.
- Establish renewable assortment standards for increasing percentage of renewables.
- Energy transition from traditional energy sources to renewables policies should be incorporated in favor to the client.
- Remove barrier for adding distributed sources generally to the grid, by making the transmission and distribution system open to all producers, regardless of size.
- Incorporate joint manufacturing policy of renewable appliance between expertise and country of origin.
- Reform the environmental policies to encourage small company to replace existing, polluting technology with clean renewables.

6.3.3. Market facilitation activities [78,149,150]

The long-time reliable availability ($>$20 years) of the system performance is the key requirement of the end-user of renewable power technologies.

- Viable choice of available configurations to suit the consumers' needs and affordability.
- Economy of scale in production.
- Stimulation of customers demand.
- Adequate means of providing regular and proper maintenance and supplying spare parts.

Dust is a major problem with solar panels. The efficiency drops drastically even when a small portion is blocked by a leaf or a thin film of dust. It was reported by Sulaiman et al. [151] that the accumulated dust on the surface of photovoltaic solar panel can reduce the system's efficiency by up to 50%. It is therefore essential to maintain them with regular cleaning at least every other day. Hence, in practice, dust must be removed from the surface of solar PV panel in order to ensure highest performance. However, the manual cleaning is a far more inexpensive option. Recently, removal of dust by coating the surface of the machine of solar panel with electrodes of indium tin oxide has been developed for mars roving machines [152,153]. Indium tin oxide is transparent, electrically sensitive material and act as electronic sensors. The sensor monitors dust levels and effectively removes the dust by shaking. This process can remove 90% of dust in 2 min and requires very little electricity. This may be the alternative suitable option for Bangladesh to remove dust form solar panels.

6.3.4. Research and development and purchasing [7,154,155]

Create incentives for private sector research and development in renewables.

- Target governmental research and development to solve systems' problems and address technological issues that are unlikely to draw the attention of companies in the private sector.
- Expand governmental purchases of renewably generated electricity, fuels and heat.

7. Energy and economic development

Energy is the basic prerequisite of a country's economic development. The Energy Information Administration (EIA) reported that the modern energy services are crucial to human well-being and to a country's economic development [156]. The indicator of a nation's stage of development, as reported by World Bank, is defined by the energy ratio, GDP/t oil equivalent (USD/toe) [157]. It was reported that the electricity is the most versatile and highly valued form of energy among the different forms of energy [158]. Several studies have been conducted to examine the causal relationship between electricity consumption and economic growth to understand their nature of relationship for policy purposes. Ferguson et al. [159], studied on the electricity use and economic development and concluded that the economic development occurred with an increase in the proportion of energy used in the form of electricity. The electricity consumption have strongest influence on country's economy, as reported by Burney [158]. The observation somewhat analogous to that observed by Jumbe et al. [160] who attempted to study the cointegration and causality between electricity consumption and GDP. The supply of electricity is vitally important to meet the growing electricity consumption, hence to sustain the economic growth in Turkey [161]. A similar observation has been reported by Ghosh [162] who studied on electricity consumption and economic growth in India. Moritomo and Hope [163] agree quite well with the observations reported by Ghosh [156]. It was concluded by Yoo [164] the increase in electricity consumption directly affects economic growth and that economic growth also stimulates further electricity consumption. A somewhat related conclusion has been reached by Han et al. [165] who attempt to study the role of the four electric power sectors in the Korean national economy: an input–output analysis. Based on the result reported by previous researchers, it is reasonable to state that no empirically based study has shown that developing countries can achieve prosperity without large increases in demand for energy, even with strong assumptions about improvements in technology, including energy efficiency.

Several researchers have been attempted to assess the linkage between per capita GDP and per capita electricity consumption in the context of Bangladesh. Asaduzzaman and Billah [166] explored the historical relationship between energy consumption and economic growth for Bangladesh. It was concluded by Asaduzzaman and Billah [166] that the level of energy use had been positively related to the level of growth and higher level of

development was known to entail higher level of energy use. It has been shown by other researchers [167] that the existent of unidirectional causal relationship exists between electricity generation and economic growth in Bangladesh. It was suggested by Sarker and Alam [167], that policies and strategies for increasing electricity generation can be implemented for speeding up of economic growth in the country. Further, it has been concluded by Mozumder and Marathe [9] that the well-designed conservation policy can play an effective role in managing the energy sector. Achieving energy efficiency by adopting different energy conservation measures can make more energy available for economic activity and reduce the economic losses incurred by the shortage of energy supply. Shrestha et al. [168] in their discussion of the comparison of institutional reforms and electricity access between Bangladesh and Thailand have emphasized the inadequate rural electrification in Bangladesh and suggested that economic growth in Bangladesh is lower which would have affected the availability of investment resources for expanding generation capacity and grid extension. Recently, studying on the relationship between economic growth, electricity consumption and investment for Bangladesh through co-integration and causality analysis over the period 1981–2011, Masuduzzaman [169] reported that the boost up of country's economy depend on not only the increment capacity of electricity generation but also the creating business friendly environment to encourage local as well as overseas investors in Bangladesh.

In order to avoid any adverse effects of electricity shortage on economic activities, it was recommended by Masuduzzaman [169] to increase new power generating capacity to satisfy the increasing demand for electricity. The Government of Bangladesh has taken initiative to design a comprehensive PSMP to raise its electricity generation of 35,000 MW by 2030, from the current generation of around 4000 MW [169]. An estimated US$13 billion investment including a USD 7 billion debt financing would be required to implement the PSMP. Any realistic plan for a self-sustaining and dynamic industrial system has to provide for overcome energy crisis in Bangladesh. However, without eradication of corruption, such renovation of the power sector will open an opportunity again for pilferage of foreign aid.

8. Conclusion

In view of the plight of the power sector in Bangladesh, it is necessary to take up with all seriousness, measures to improve capacity addition to maximize power generation into balance supply and increasing power demand by different categories of consumers. The power sector alone cannot be blamed for its lapses and failures. Consumers, for whose benefit the corporation strives, have their share of responsibility. Consumers have to be responsible and must not take to unethical practice and malpractices such as illegal tapping of power, and unauthorized use of power. The country is heavily dependent on expensive imported energy resources, especially diesel oil as primary energy sources that place a big burden on the country's economy. However, government plan to construct coal fired power plant in the near future due to the abundance of coal reserves in Bangladesh. It is strongly recommended to apply clean coal technology to decrease emission production from thermal power plant. Thus, the construction of new power plants in the near future may solve electricity shortages in the country. In addition, the government has considered to set up a nuclear power plant, which may be another option to solve the country's energy crisis to some extent. However, the increase of fuel consumption will give rise to the level of emissions that are dangerous to human health. In this regard, renewable energy resources appear to be the one of the most efficient and effective solutions for clean and sustainable energy development in Bangladesh. The country has enormous potential for the production of solar power, biofuel and biomass energy. However, vigorous action is required to implement these energy technologies to the rural excess of the country. Unless power is sufficiently available to the industrial sector, the state cannot be progress industrially. Industrial backwardness in today's world is an indication of economic backwardness. Therefore availability of sufficient power is an index of economic development. A first step to facilitate expansion of rural access as part of an energy sector reform should be to revise the existing country's energy policy framework. The private sector can play an important role to promote the dissemination of the country's renewable energy sector. Thus, how to maximize private sector investment is a key issue in Bangladesh to achieve a greater equity in renewable energy sector. In these cases, several institutional changes are necessary in the energy sector to give the private sector a larger role and to stimulate the creation of sustainable energy markets. It is also crucial to design subsidies with careful attention to reach the poorest segments of rural population. Business friendly policies and regulations need to be formulated to encourage private participation. Further, initiatives should be taken to bring about improvements in the efficiency of delivery systems. After all, achieving a sustainable energy system requires comprehensive reforms in the power sector, which represent one of the most crucial investments of the 21st century in Bangladesh.

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